"Express Mail" label number:EL 738 149 399 US

Date of Deposit: AUGUST 31, 2001

PATENT

Case No. DP No. 304183

(7500/60)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTOR(S): BRUNO P.B. LEQUESNE
AVOKI M. OMEKANDA
SYED A. HOSSAIN
HARALD KLODE
JIN-JAE CHEN

TITLE: SWITCHED-RELUCTANCE
MOTOR CONTROL

ATTORNEYS: SCOTT A. MCBAIN, ESQ.
DELPHI TECHNOLOGIES, INC.
LEGAL STAFF
P.O. BOX 5052
MAIL CODE: 480-414-420
TROY, MICHIGAN 48007-5052
(248) 267-5514

DP-304183

SWITCHED-RELUCTANCE MOTOR CONTROL

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention generally relates to a control of a switched-reluctance motor. The present invention specifically relates to a brake-by-wire system having a switched-reluctance motor that is controlled during a pre-alignment braking phase, a preliminary braking phase, and a primary braking phase.

2. DESCRIPTION OF THE RELATED ART

Switched-reluctance motors are emerging as a prime candidate for various applications (e.g., automotive brake applications), because switched-reluctance motors provide an advantage of a large peak-torque capability on an intermittent basis and an advantage of a large speed range. Additionally, switched-reluctance motors have inherent fault tolerant features.

A switched-reluctance motor operates on the principle of variable reluctance, and typically includes a stator pole, a plurality of windings, and a rotor, such as a stator **20**, windings **31-38**, and a rotor **40** forming a 4-phase, 8 stator pole/6 rotor pole switched-reluctance motor as shown in **FIGS. 1A-1D**. Stator **20** includes stator poles **21-28**, and rotor **40** includes rotor poles **41-46**. Windings **31-38** are wrapped around stator poles **21-28**, respectively.

Winding **31** and winding **35** are electrically coupled (not shown) to define a phase A of the motor whereby a phase current flowing through winding **31** and winding **35** generates diametric magnetic fields around stator pole **21** and stator pole **25**. Winding **32** and winding **36** are electrically coupled (not shown) to define a phase B of the motor whereby a phase current flowing through winding **32** and winding **36** generates diametric magnetic fields around stator pole **22** and stator pole **26**. Winding **33** and winding **37** are electrically coupled (not shown) to define a

phase C of the motor whereby a phase current flowing through winding **33** and winding **37** generates diametric magnetic fields around stator pole **23** and stator pole **27**. Winding **34** and winding **38** are electrically coupled (not shown) to define a phase D of the motor whereby a phase current flowing through winding **34** and winding **38** generates diametric magnetic fields around stator pole **24** and stator pole **28**.

Rotor **40** is typically made of iron, and as a result, rotor **40** can be rotated about an axis **40a** in response to a generation of one or more pairs of diametric magnetic fields. Phase currents are therefore strategically provided to windings **31-38** to thereby rotate rotor **40** about axis **40a** in a clockwise direction or in a counterclockwise direction. Stator **20**, windings **31-38**, and rotor **40** are housed within a system (e.g., a electrically-actuated brake system) with the rotor **40** being coupled to an actuating member (e.g., a planetary gear assembly) of the system whereby the actuating member concurrently rotates about axis **40a** in response to any rotation of rotor **40** about axis **40a**.

Various complicated phase current control schemes have been devised for determining a rotational position of rotor **40**, for rotating rotor **40** over a large speed range, for avoiding local overheating of the switched-reluctance motor, and for minimizing the ampere levels of the phase currents. The present invention addresses a need for a simplified phase current control scheme for comprehensively controlling a positioning and a rotation of rotor **40** about axis **40a**.

SUMMARY OF THE INVENTION

One form of the present invention is method of controlling an operation of a switched-reluctance motor including a stator having a stator pole and a rotor having a rotor pole. First, the rotor pole and the stator pole are aligned in response to a reception of an actuation command. Second, the rotor is cranked in a direction dictated by the actuation command for a predetermined time period. Third, the rotor is rotated to a holding position upon an expiration of the predetermined time period. Finally, any operational losses of the switched-reluctance motor are minimized when the rotor is in the holding position.

A second form of the present invention is a device for controlling an operation of a switched-reluctance motor including a stator having a stator pole and a rotor having a rotor pole. The system comprises the following means. A means for aligning the rotor pole and the stator pole in response to a reception of an actuation command. A means for cranking the rotor in a direction dictated by the actuation command for a predetermined time period. A means for rotating the rotor to a holding position upon an expiration of the predetermined time period. And, a means for minimizing any operational losses of the switched-reluctance motor when the rotor is in the holding position.

A third form of the present invention is a switched-reluctance motor including a stator having a stator pole, and a rotor having a rotor pole. The switched-reluctance motor further comprises the following means. A means for aligning the rotor pole and the stator pole in response to a reception of an actuation command. A means for cranking the rotor in a direction dictated by the actuation command for a predetermined time period. A means for rotating the rotor to a holding position upon an expiration of the predetermined time period. And, a means for minimizing any operational losses of the switched-reluctance motor when the rotor is in the holding position.

The foregoing forms, and other forms, features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8 stator pole/6 rotor pole switched-reluctance motor with phase A aligned;

FIG. 1B is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8-stator pole/6 rotor pole switched-reluctance motor with phase B aligned;

FIG. 1C is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8-stator pole/6 rotor pole switched-reluctance motor with phase C aligned;

FIG. 1D is a diagrammatic cross-sectional view of a stator pole, windings, and a rotor of a prior art 4-phase, 8-stator pole/6 rotor pole switched-reluctance motor with phase D aligned;

FIG. 2 is block diagram of one embodiment of a control device of the present invention;

FIG. 3 is flow chart of one embodiment of a master control routine implemented by the **FIG. 2** control device;

FIG. 4A is flow chart of a first embodiment of a pre-alignment control routine implemented by the **FIG. 2** control device;

FIG. 4B illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 4A** pre-alignment control routine;

FIG. 5A is flow chart of a second embodiment of a pre-alignment control routine implemented by the **FIG. 2** control device;

FIG. 5B is a first exemplary graph of a torque characteristic of the rotor of the **FIG. 1** switched-reluctance motor versus a rotational position of the rotor;

FIG. 5C illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 5A** pre-alignment control;

FIG. 6A is flow chart of one embodiment of a preliminary control routine implemented by the **FIG. 2** control device;

FIG. 6B illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 6A** preliminary control routine;

FIG. 7A is flow chart of one embodiment of a primary control routine implemented by the **FIG. 2** control device;

FIG. 7B illustrates exemplary graphs of phase currents employed during an implementation of the **FIG. 7A** primary control routine;

FIG. 8A is flow chart of a second embodiment of primary control routine implemented by the **FIG. 2** control device;

FIG. 8B is a second exemplary graph of a torque characteristic of the rotor of the **FIG. 1** switched-reluctance motor versus a rotational position of the rotor; and

FIG. 8C illustrates an exemplary graph of a phase current employed during an implementation of the **FIG. 8A** primary control routine.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

A control device **50** of the present invention is shown in **FIG. 2**. Control device **50** comprises a controller **51** and a switched-reluctance motor interface **54**. Control device **50** optionally comprises a rotor position sensor **55**.

Controller **51** is preferably an electronic circuit comprised of one or more components that are assembled as a common unit within a system (e.g., a electrically-actuated brake system). Alternatively, for the multiple component embodiments, one or more of these components may be distributed throughout the system housing controller **51**. Controller **51** may be comprised of digital circuitry, analog circuitry, or both. Also, controller **51** may be programmable, a dedicated state machine, or a hybrid combination of programmable and dedicated hardware. To implement the principles of the present invention, controller **51** can further include any control clocks, interfaces, signal conditioners, filters, Analog-to-Digital (A/D) converters, Digital-to-Analog (D/A) converters, communication ports, or other types of operators as would occur to those having ordinary skill in the art.

In one embodiment, controller **51** includes a microprocessor **52** operatively coupled to one or more solid-state memory devices **53**. Microprocessor **52** is preferably a microprocessor from one the Intel, AMD, or Motorola families of microprocessors. Memory **53** is one or more computer readable mediums (e.g., a read-only memory, an erasable read-only memory, a random access memory, a compact disk, a floppy disk, a hard disk drive, and other known forms) that are electrically, magnetically, optically or chemically altered to contain computer readable code corresponding to a master control routine **60** (**FIG. 3**) for intelligently providing a commutation control signal **CC_S** to interface **54**, and is arranged for reading and writing of data in accordance with the principles of the present invention. In alternative embodiments of controller **51**, the computer program product corresponding to master control routine **60** (**FIG. 3**) can otherwise be partially or fully implemented by digital circuitry, analog circuitry, or both (e.g., an application specific integrated circuit (ASIC))

Switched-reluctance motor interface **54** receives commutation control signal **CC_S** from controller **51**. In response thereto, switched-reluctance motor interface **54** is designed to conventionally commutate, separately or concurrently, one or more phases A-D of windings **31-38** to thereby control a rotation of rotor **40** (**FIG. 1**) about axis **40a** (**FIG. 1**). Specifically, interface **54** provides a phase current signal **I_{PS1}** as commanded by commutation control signal **CC_S** through winding **31** and winding **35**, a phase current signal **I_{PS2}** as commanded by commutation control signal **CC_S** through winding **32** and winding **36**, a phase current signal **I_{PS3}** as commanded by commutation control signal **CC_S** through winding **33** and winding **37**, and a phase current signal **I_{PS4}** as commanded by commutation control signal **CC_S** through winding **34** and winding **38**. Those having ordinary skill in the art will appreciate the various embodiments of interface **54** as known in the art, such as, for example, an arrangement of switches in the form of MOSFET transistors.

When rotor position sensor **55** is included within control device **50**, rotor position sensor **55** conventionally provides a position detection signal **PDs** to controller **51**. Position detection signal **PDs** is indicative of a sensed rotational position of rotor **40** (**FIG. 1**) whereby controller **51** can conventionally estimate the position of rotor **40**. Those having ordinary skill in the art will appreciate the various embodiments of rotor position sensor **55** as known in the art, such as, for example, an arrangement of Hall Effect sensors, encoders, and the like. Alternatively, when rotor position sensor **55** is excluded from control device **50**, interface **54** implements algorithms known in the art to estimate the position of rotor **40** as a function of phase currents $\mathbf{I_{PS1\text{-}PS4}}$.

Referring additionally to **FIG. 3**, routine **60** comprises a pre-alignment stage **S62**, a preliminary stage **S64** and a primary stage **S66**. Routine **60** is described herein in conjunction with the 4-phase 8 stator pole/6 rotor pole switched-reluctance motor shown in **FIGS. 1A-1D**. Those having ordinary skill in the art however will appreciate the applicability of routine **60** to other types of switched-reluctance motors.

During stage **S62**, controller **51** executes a pre-alignment routine **70** as shown in FIG. **4A** in one embodiment of routine **60** and a pre-alignment routine **80** as shown in FIG. **5A** in another embodiment of routine **60**. Routines **70** and **80** are for aligning one of the rotor poles **41-46** (FIG. 1) with one of the stator poles **21-28** (**FIG. 1**) in response to an actuation command **AC** from a device (e.g., a brake-by-wire controller) (not shown) of a system housing control device **50**.

Referring to **FIGS. 1A-1D**, **4A**, and **4B**, during a stage **S72** of routine **70**, controller **51** identifies a target phase for defining an initial position of rotor **40**. In one embodiment, the identification of the target phase is retrieved from memory **53**. For example, microprocessor **52** can retrieve from memory **53** the identification of phase A (**FIG. 1A**) as the target phase.

During a stage **S74** of routine **70**, controller **51** controls an excitement of a phase adjacent to the target phase to thereby position rotor **40** whereby the target phase is misaligned. The excitation is accomplished by controller **51** directing interface **54** via commutation control signal **CCs** to provide a corresponding phase current to the corresponding windings. For example, when phase A is the target phase, phase A may be aligned (i.e., a pair of rotor poles being aligned with stator pole **21** and stator pole **25**) as shown in **FIG. 1A**; phase A may be unaligned (i.e., a pair of rotor poles being equidistant from stator pole **21** and another pair of rotor poles being equidistant from stator pole **25**) as shown in **FIG. 1C**; or phase A may be misaligned (i.e., neither aligned or unaligned) as shown in **FIGS. 1B** and **1D**. Interface **54** directs a flow of a phase current $\mathbf{I_{PS2}}$ at an ampere level $\mathbf{X_1}$ through winding **32** and winding **36** for a time period $\mathbf{t_1}$ as shown in **FIG. 4B** to thereby rotate rotor **40** to a position whereby phase B is aligned (i.e., a pair of rotor poles being aligned with stator pole **22** and stator pole **26**) as shown in **FIG. 1B**; or phase B is unaligned position (i.e., a pair of rotor poles being equidistant from stator pole **22** and another pair of rotor poles being equidistant from stator pole **26**) as shown in **FIG. 1D**. As a result, phase A is misaligned as shown in **FIG. 1B** or **FIG. 1D**.

During a stage **S76** of routine **70**, controller **51** controls an excitement of the target phase to thereby position rotor **40** whereby the target phase aligned. The excitation is accomplished by controller **51** directing interface **54** via commutation control signal **CCs** to provide a corresponding phase current to the corresponding windings. For example, when phase A is the target phase, interface **54** directs a flow of a phase current $\mathbf{I_{PS1}}$ at ampere level $\mathbf{X_1}$ through winding **31** and winding **35** for a time period $\mathbf{t_2}$ as shown in **FIG. 4B** to thereby rotate rotor **40** to a position whereby phase A is aligned as shown in **FIG. 1A**.

Controller **51** returns to routine **60** upon completion of stage **S76**. Those having ordinary skill in the art will appreciate that a benefit of routine **70** is the capability of controller **51** to subsequently control a cranking of rotor **40** in a desired direction. Referring to **FIGS. 1A-1D**, and **5A-5C**, during a stage **S82** of routine **80**, controller **51** identifies a target position for defining an initial position of rotor **40**. In one embodiment of stage **S82**, the target position is selected as a function of maximizing the torque level experienced by an actuating member (e.g., a planetary gear system) being coupled to rotor **40** when rotor **40** is in the initial position, and the identification of the target position is retrieved from memory **52** by microprocessor **51**. For example, as shown in **FIG. 5B**, a simulated rotation of rotor **40** can indicate a position of -23 from an alignment of phase A that provides the maximum torque level to the actuating member, and a rotation of rotor **40** from the -23 position of phase A aligned in a counterclockwise direction facilitates a minimum response time by rotor **40**. Accordingly, the -23 position of phase A aligned is stored in memory **53** as the target position.

During a stage **S84** of routine **80**, controller **51** controls an alignment of a phase adjacent the target position. In one embodiment of stage **S84**, controller **51** implements routine **70** during stage **S84** as previously described herein. For example, phase D is adjacent the -23 position of phase A aligned and interface **54** therefore directs a flow of phase current I_{PS3} through winding **33** and winding **37** during stage **S74** to thereby rotate rotor **40** to a position whereby phase D is misaligned as shown in **FIG. 1A** or in **FIG. 1C**. Interface **54** thereafter directs a flow of phase current I_{PS4} through winding **34** and winding **38** during stage **S76** to thereby rotate rotor **40** to a position whereby phase D is aligned as shown in **FIG. 1D**.

During a stage **S86** of routine **80**, controller **51** controls an excitement of two or more phases remote from the target position. The excitation is accomplished by controller **51** directing interface **54** via commutation control signal CC_S to provide corresponding phase currents to the corresponding windings with a differential ampere level between the phase currents of the remote phases. For example, phase A and phase B are the phases that are remote the -23 position of phase A aligned and interface **54** therefore directs a flow of phase current I_{PS1} through winding **31** and winding **35** at an ampere level X_2 for a time period t_3 and a flow of phase current I_{PS2} winding **32** and winding **36** at ampere level X_1 for time period t_3 to thereby rotate rotor **40** to the -23 position of phase A aligned as shown in **FIG. 5B**.

In an alternative embodiment of stage **S86**, controller **51** utilizes the position detection signal P_{DS} from sensor **55** during stage **S84** and stage **S86** to direct interface **54** via commutation control signal CC_S to provide the appropriate phase current(s) whereby rotor **40** is rotated to the -23 position of phase A aligned as shown in **FIG. 5B**.

Controller **51** returns to routine **60** upon completion of stage **S86**. Those having ordinary skill in the art will appreciate that benefit of routine **80** is the capability of controller **51** to subsequently control a cranking of rotor **40** in a desired direction within a minimized response time.

Referring to **FIGS. 2** and **3**, controller **51** proceeds to stage **S64** of routine **60** upon a completion of stage **S62**. During stage **S64**, controller **51** executes a preliminary control routine **90** as shown in **FIG. 6A**.

Referring to **FIGS. 1A-1D**, **6A** and **6B**, during a stage **S92** of routine **90**, controller **51** cranks rotor **40** in a desired direction for a predetermined time period. In one embodiment of stage **S92**, controller **51** controls a sequential excitement of phases for one or more cycles to thereby crank rotor **40** in a desired direction (e.g., in a direction of a holding position corresponding to a predetermined range of rotation from the initial position) as dictated by the actuation command **AC**. The sequential excitation is accomplished by controller **51** directing interface **54** via commutation control signal CC_S to sequentially provide corresponding phase currents to the corresponding windings for one or more cycles. For example, as

shown in **FIG. 6B**, when phase A aligned represents the initial position of rotor **40** and the holding position is in a counterclockwise direction therefrom, interface **54** directs a flow of phase current I_{PS2} through winding **32** and winding **36** for a time period t_4 to thereby excite phase D whereby rotor **40** rotates in a counterclockwise direction. Interface **54** then directs a flow of phase current I_{PS3} through winding **33** and winding **37** for a time period t_5 to thereby excite phase C whereby rotor **40** continues to rotate in a counterclockwise direction. Interface **54** then directs a flow of phase current I_{PS4} through winding **34** and winding **38** for a time period t_6 to thereby excite phase B whereby rotor **40** continues to rotate in a counterclockwise direction. Interface **54** then directs a flow of phase current I_{PS1} through winding **31** and winding **35** for a time period t_7 to thereby excite phase A whereby rotor **40** continues to rotate in a counterclockwise direction. The sequential excitation of one or more phases B-C-D-A can be repeated as needed for rotor **40** to crank rotor **40** in the desired direction (e.g., a direction of a holding position).

In one embodiment of stage **S92**, each time period $t_{4\text{-}7}$ is fixed at a particular level (e.g., 2 milliseconds). In a second embodiment of stage **S92**, each time period $t_{4\text{-}7}$ is fixed at one or more various levels (e.g., t_4 being 2 milliseconds, t_5 being 1.8 milliseconds, t_6 being 1.6 milliseconds, and t_7 being 1.4 milliseconds). In a third embodiment of stage **S92**, controller **51** dynamically determines the levels of time periods $t_{4\text{-}7}$ as a function of operating parameters of the motor as would occur to those having ordinary skill in the art, such as, for example, any load torque applied by the motor, a power supply for the motor, a temperature of the motor, and a responsiveness level of the motor to the phase currents $I_{PS1\text{-}PS4}$.

Upon expiration of the predetermined time period during stage **S92**, controller **51** proceeds to stage **S94** of routine **90** to execute high speed routines as well known in the art whereby rotor **40** is rotated in the desired direction. Controller **51** terminates routine **90** upon completion of stage **S94**. In one embodiment of stage **S94**, rotor **40** is rotated until rotor **40** is positioned in a holding position.

Referring to **FIGS. 2** and **3**, controller **51** proceeds to stage **S66** of routine **60** to execute a primary control routine **100** as shown in **FIG. 7A** and a primary control routine **110** as shown in **FIG. 8A**. Routines **100** and **110** are for minimizing any heating losses and any current losses, respectively, of the switched-reluctance motor when rotor **40** is positioned in the holding position.

Referring to FIGS. **1A-1D**, **2**, **7A** and **7B**, during a stage **S102** of routine **100**, controller **51** determines if rotor **40** is in the holding position. In one embodiment of stage **S102**, controller **51** determines rotor **40** is in the holding position when a load force signal $\mathbf{LF_S}$ indicates an actual load force on the actuating member approximates a desired load force on the actuating member that corresponds to the holding position as indicated by the actuation command **AC**. Load force signal $\mathbf{LF_S}$ is provided to controller **51** by sensors known in the art.

Controller **51** proceeds to a stage **S104** of routine **100** when controller **51** determines if rotor **40** is in the holding position during stage **S102**. During stage **S104**, controller **51** determines if rotor **40** has been in the holding position for a predetermined time period. In one embodiment of stage **S104**, interface **54** includes an arrangement of switches and either controller **51** or interface **54** includes a counter. The counter is utilized to count the time a particular switch corresponding to the holding position is turned on. When controller **51** determines rotor **40** has been in the holding position for a predetermined time period, controller **51** proceeds to a stage **S106** of routine **100** to control a dithering of rotor **40**.

In one embodiment of stage **S106**, controller **51** directs interface **54** to sequentially excite phases adjacent the holding position for one or more time cycles. The sequential excitation is accomplished by controller **51** directing interface **54** via commutation control signal $\mathbf{CC_S}$ to sequentially provide corresponding phase currents to the corresponding windings for one or more cycles. For example, when the holding position corresponds to phase A aligned as shown in **FIG. 1A** and rotor **40** was rotated in a counterclockwise direction to the holding position, interface **54** directs a flow of phase current $\mathbf{I_{PS4}}$ through winding **34** and winding **38** for a predetermined time period to thereby excite phase D whereby rotor **40** is rotated in a clockwise direction. Interface **54** then directs a flow of phase current $\mathbf{I_{PS1}}$ through

winding **31** and winding **32** for a predetermined time period to thereby again excite phase A whereby rotor **40** is rotated back to the holding position in a counterclockwise direction. The cycle of sequentially exciting phases D-A can be repeated as needed. In a second embodiment of stage **S105**, one or more cycles of sequentially exciting D-C-D-A is repeated as needed. In a third embodiment of stage **S106**, one or more cycles of sequentially exciting D-C-B-C-D-A is repeated as needed.

In a fourth embodiment of stage **S106**, controller **51** controls a decrease in excitation of a phase corresponding to the holding position while maintaining a motor torque level corresponding to the holding position. This is accomplished by controller **51** directing interface **54** via commutation control signal **CC_S** to decrease the ampere level of the phase current corresponding to the excited phase and to initiate the flow of a phase current through an adjacent phase at an ampere level that will maintain the motor torque level. The motor torque level is a function of the design of the switched-reluctance motor, and controller **51** can therefore determine the motor torque level from a lookup table stored within memory **53**.

For example, as shown in **FIG. 7B**, when the holding position corresponds to phase A aligned as shown in **FIG. 1A** and rotor **40** was rotated in a counterclockwise direction to the holding position, interface **54** directs a flow of phase current $\mathbf{I_{PS1}}$ through winding **31** and winding **35** at an ampere level $\mathbf{X_1}$ for a time period $\mathbf{t_8}$ to excite phase A. Subsequently, interface **54** directs a flow of phase current $\mathbf{I_{PS1}}$ through winding **31** and winding **35** at an ampere level $\mathbf{X_2}$ that is lower than ampere level $\mathbf{X_1}$ during a time period $\mathbf{t_9}$. Concurrently during time period $\mathbf{t_9}$, interface **54** directs a flow of phase current $\mathbf{I_{PS2}}$ through winding **32** and winding **34** at ampere level $\mathbf{X_2}$ to thereby simultaneously excite phase A and phase B.

A fifth embodiment of stage **S106** involves a modification of the fourth embodiment of stage **S106** whereby the motor torque level as retrieved from memory **53** is undulated about a fixed level after a fixed period of time. The ampere levels of phase currents being supplied to the two phases are adjusted accordingly as appreciated by those having ordinary skill in the art.

Controller **51** returns to routine **60** upon completion of stage **S106**. Those having ordinary skill in the art will appreciate that benefit of routine **100** is the capability of controller **51** to prevent local overheating of stator **20**, windings **31-38**, and rotor **40**. As a result, stress within windings **31-38** and an uneven resistance variation of the phases are minimized.

Referring to FIGS. **1A-1D**, **2**, and **8A-8C**, during a stage **S112** of routine **110**, controller **51** determines the holding position of rotor **40** as previously described herein in connection with stage **S102** **(FIG. 7A)**. During a stage **S114** of routine **110**, controller **51** determines a motor torque corresponding to the holding position of rotor **40**. In one embodiment, controller **51** retrieves the motor torque from a lookup table in memory **53**. For example, as shown in **FIG. 8B**, controller **51** can retrieve a motor torque level corresponding to an intersection of a holding position A corresponding to phase C aligned **(FIG. 1C)** and a motor torque curve **MTC_1**.

During a stage **S116** of routine **110**, controller **51** controls a reduction of an ampere level of a phase current corresponding to the holding position of rotor **40**. The reduction in ampere level is accomplished by controller **51** directing interface **54** via commutation control signal **CC_S** to reduce the ampere level of the excited phase current. In one embodiment of stage **S116**, the adjustment of the ampere level maintains a motor torque level that is greater than the load torque being applied to the actuating member coupled to rotor **40**.

For example, as shown in **FIG. 8C**, when phase C aligned corresponds to the holding position, interface **54** directs a flow of phase current **I_{PS3}** at an ampere level **X_1** through winding **33** and winding **37** for time period **t_{10}** to maintain rotor **40** in the holding position. Thereafter, interface **54** then directs a flow of phase current **I_{PS3}** at an ampere level **X_2** through winding **37** and winding **37** for time period **t_{11}** to thereby establish a level of motor torque corresponding to an intersection of a position B of rotor **40** and a motor torque curve **MTC_2** as shown in **FIG. 8B** while maintaining rotor **40** in the holding position.

Controller **51** returns to routine **110** upon completion of stage **S116**. Those having ordinary skill in the art will appreciate that a benefit of routine **110** is a minimization of current while maintaining rotor **40** in a holding position.

Referring again to **FIG. 3**, routine **60** as described herein is intended to be utilized in systems requiring pre-alignment stage **S62**, preliminary stage **S64** and primary stage **S66**, such as, for example, an electric caliper brake system. Nevertheless, one of the stages **S62-S66** of routine **60** can be individually implemented within a system, and two of the stages **S62-S66** of routine **60** can be jointly implemented within a system. Also, any embodiments of the various embodiments of stages **S62-S66** such as routine **70 (FIG. 4A)**, routine **80 (FIG. 5A)**, routine **90 (FIG. 6A)**, routine **100 (FIG. 7A)** and routine **110 (FIG. 8A)** can be individually or jointly implemented within systems.

While the embodiments of the present invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.